United States General Accounting Office

GAO

Report to the Chairman, Legislation and National Security Subcommittee, Committee on Government Operations, House of Representatives

July 1989

TEST AND EVALUATION

Reducing Risks to Military Aircraft From Bird Collisions

GAO/NSIAD-89-127

(4)

GAO

United States
General Accounting Office
Washington, D.C. 20548

National Security and
International Affairs Division

B-222886

July 13, 1989

The Honorable John Conyers, Jr.
Chairman, Legislation and National
Security Subcommittee,
Committee on Government Operations
House of Representatives

Dear Mr. Chairman:

This report responds to the former Chairman's February 10, 1988, request concerning military aircraft testing against bird collisions[1] and development of nonflammable hydraulic fluid. We specifically reviewed (1) the extent of bird collision damage to military aircraft, (2) the specifications for testing engines against bird collisions, (3) the relationship between engine contractors and the government during tests to identify risks from bird collisions, and (4) the development and use of nonflammable hydraulic fluid to reduce risks from fires.

We also reviewed some nontesting measures to reduce the risk to military aircraft, such as bird avoidance efforts and the redesign of aircraft transparencies[2] to withstand bird collisions. The information we developed on these nontesting measures is contained in appendix III.

Bird Collisions Can Have Serious Consequences

Birds are a serious threat to all aircraft—especially to military aircraft that fly fast and low where birds are more likely to be a hazard. From 1983 to 1987, military aircraft have collided with birds over 16,000 times. Although many of these collisions caused only minor damage, the services lost six crew members, incurred $318 million in damages, and lost nine aircraft.[3] Since we started our study in March 1988, two more aircraft (F-16s) have been lost to bird collisions.

Although the losses from bird collisions have been small compared to the total acquisition costs for military aircraft, total flying hours, and total number of bird collisions, these losses are still significant because

[1] Throughout this report, "bird collisions" represent any impact between a bird and a military aircraft. The military classifies collisions as either strikes to aircraft structures or ingestions into engines.

[2] "Transparencies" are the clear panels used to see out of the cockpit (i.e., the windscreen, the canopy, and side windows).

[3] The Air Force lost six aircraft, the Navy lost two, and the Army lost one.

of the loss of human life and valuable weapon systems. With more expensive aircraft coming into use, such as the B-1B and B-2, the dollar value of these losses could become more significant.

Realistic Testing Is Important

Realistic aircraft testing can provide decisionmakers with useful data to evaluate the risks associated with natural hazards, such as birds, and the compromises that may have to be made to sustain a particular level of performance, such as aircraft speed. Decisionmakers have not had adequate information available because

- the specifications for testing jet engines against bird collisions do not reflect the sizes and the numbers of birds being ingested;
- the services are not testing airframes[1] to identify and minimize vulnerability to bird collisions; and
- government oversight of engine testing to withstand bird ingestions has been limited, and documentation has been insufficient to evaluate test effectiveness.

Specifications and Testing for Jet Engines Do Not Reflect the Sizes and the Number of Birds Ingested

Air Force and Navy test specifications for jet engines serve as guidance rather than as requirements to determine the testing called for in a contract. These tests may range from using analytical methods, such as computer analysis, to the actual firing of birds into an engine. If an engine is similar to a model previously tested, the services may waive testing.

Our review of test documentation for nine engines revealed that engines were not always fully tested against known bird hazards because the guidance in the specifications allows for flexibility. Some tests used smaller birds than those specified; sometimes engines were not tested against medium or large birds; and sometimes engines were accepted by the government without any bird ingestion testing. (See app. IV.)

Recent studies show that the Air Force and the Navy weight specifications for medium birds were not representative of the size birds actually being ingested. In addition, although only one bird is usually ingested, Air Force and Navy specifications cite a need to test the ingestion of several birds at once. We were told the Air Force is planning to change its specifications for bird ingestion testing. Further, we were advised

[1]Airframe refers to the aircraft's exterior, excluding engines and transparencies. Examples of critical airframe areas susceptible to bird collisions are the fuselage and the wing's leading edges.

that the services are developing a common specification for testing similar jet engines. If these changes are made, they should resolve the discrepancy between specifications and recorded experience.

Airframes Are Not Tested to Withstand Bird Collisions

Although about half of all the recent reports on military collisions with birds involved the airframe (see table I.3), officials told us that airframes are not tested against bird hazards and that no specifications require such testing.

Officials in the Office of the Secretary of Defense (OSD) agreed that a requirement may be needed to test the resistance of critical airframe areas to bird collisions. However, OSD and service officials disagree on whether testing done to predict aircraft vulnerability to enemy projectiles would be sufficient to ensure resistance to bird collisions.[5]

DOD Oversight of Contractor Testing Has Been Limited

The services' role in testing aircraft against bird collisions is limited primarily to monitoring. The engine and the transparency are the only parts of military aircraft required to be tested against bird collisions. Officials described the military's role in testing both parts as being basically the same—the contractor performs the testing and the military monitors the test process. We concentrated our work on the government's observation of engine testing against bird ingestions. The services review and approve the contractors' test plans and reports and observe the contractors' actions, relying on the contractors to perform the actual testing.[6] According to service representatives, OSD and the services have not provided guidance on the degree of oversight required through observation of tests or on documentation of these observations. Because we found little information on test observations, it was difficult to evaluate what military representatives have done to ensure that tests are conducted as specified and that aircraft are as bird resistant as contractually required.

[5]Live-fire testing, for example, is a form of testing done by the military to determine how well its weapon systems can withstand hits by enemy projectiles.

[6]See appendix I for a more detailed description of testing procedures.

Status of Development of Nonflammable Hydraulic Fluid

We were also asked to determine the developmental status of nonflammable hydraulic fluid. A B-1B aircraft was lost in September 1987 after a bird collided with it and the hydraulic fluid caught fire. From 1965 to 1986, the Air Force had at least five fatalities and 19 injuries and lost $237 million in aircraft accidents in which hydraulic fluid either caused fires or intensified preexisting ones.

Since the 1960s, the services have tried to develop a nonflammable hydraulic fluid compatible with existing hydraulic systems. By the early 1980s, the Air Force had developed a nonflammable hydraulic fluid, chloro-tri-fluoro-ethylene (CTFE), but it is not compatible with existing aircraft hydragulic systems.[7] To use this fluid, the Air Force is designing and testing new components for hydraulic systems. According to an Air Force Systems Command official, the cost for developing the fluid and components has amounted to at least $21 million through September 1988.

Service officials stated that they have no firm plans to use nonflammable hydraulic fluid in future aircraft. In addition, they believe that retrofitting existing aircraft would not be cost effective. Research continues for possible applications of CTFE.[8]

Recommendations

We recommend that the Secretary of Defense

- require the services to revise test specifications to reflect the sizes and the numbers of birds actually colliding with military aircraft and
- require the services to evaluate the vulnerability of critical airframe areas such as the nose and the wing's leading edges to minimize the risk from bird collisions.

Although we did not obtain formal agency comments on a draft of this report, we discussed the contents with OSD and service officials and incorporated their comments where appropriate.

[7] The Navy and the Army, recognizing CTFE as nonflammable, have ended their own efforts to develop a nonflammable aircraft hydraulic fluid.

[8] According to Air Force officials, managers for the Advanced Tactical Fighter program have been directed to consider CTFE, but it will be 2 years before design decisions will be made. Program managers for the Army's new tracked vehicles have also been given information about CTFE to consider its application.

Appendix I contains details regarding the testing of aircraft against bird collisions. Appendix II provides details on the development and use of nonflammable hydraulic fluid. Appendix III contains information regarding measures other than testing that may reduce risk to aircraft. Appendix IV lists the engines that provided the basis of our examination of engine test documentation. Our objectives, scope, and methodology are discussed in appendix V.

Unless you publicly release its contents earlier, we plan no further distribution of this report until 30 days from the date of the report. At that time we will send copies to the Secretaries of Defense, the Army, Navy, and Air Force, and make copies available to others upon request.

This report was prepared under the direction of Paul F. Math, Director, Research, Development, Acquisition, and Procurement Issues. Major contributors to this report are listed in appendix VI.

Sincerely yours,

Frank C. Conahan

Frank C. Conahan
Assistant Comptroller General

Contents

Letter		1
Appendix I Testing Military Aircraft Against Bird Collisions		8
	Frequency and Cost of Bird Collisions	8
	Aircraft Testing Process	9
	Specifications and Testing for Jet Engines Are Not Realistic	11
	Airframes Are Not Tested Against Bird Collisions	13
	DOD Performs Limited Oversight of Contractor Testing Against Bird Collisions	14
Appendix II Status on Development of Nonflammable Hydraulic Fluid		16
	Hydraulic Fluids Currently in Use	16
	Development of Nonflammable Hydraulic Fluid	16
	Plans to Use Nonflammable Hydraulic Fluid	17
Appendix III Nontesting Measures to Reduce Risk to Aircraft		18
	Reduction and Avoidance Efforts to Minimize Bird Collisions	18
	Air Force Redesign of Aircraft Transparencies When Missions Are Changed	20
Appendix IV Extent of Testing to Withstand Bird Ingestions for Nine Operational Engines		22
Appendix V Objective, Scope, and Methodology		23

Appendix VI Major Contributors to This Report

Appendix VI Major Contributors to This Report 26
National Security and International Affairs Division, Washington, D.C. 26
Norfolk Regional Office 26
Boston Regional Office 26

Tables

Table I.1: Number of Collisions Between Military Aircraft and Birds (1983-87) 8
Table I.2: Cost of Bird Collisions With Military Aircraft (1983-87) 9
Table I.3: Total Bird Strikes to Military Aircraft and Percentage of Strikes to Airframes 14
Table II.1: Air Force Cost to Develop Nonflammable Hydraulic Fluid and Components (1975-88) 17

Abbreviations

BASH	Bird Aircraft Strike Hazard
CTFE	chloro-tri-fluoro-ethylene
DOD	Department of Defense
OSD	Office of the Secretary of Defense

Testing Military Aircraft Against Bird Collisions

Natural hazards, such as hail, ice, sand, and birds can damage the structure or the engines of military aircraft, thus affecting their mission performance. Birds are especially hazardous to aircraft that fly fast and low where birds are more likely to be found. Therefore, the services should design and test their aircraft to minimize the risks presented by birds as well as to ensure successful completion of missions.

Frequency and Cost of Bird Collisions

Although military aircraft frequently collide with birds or ingest them into the engine, relatively few collisions are catastrophic. In more than 16,000 collisions reported between 1983 and 1987, the Air Force lost 6 crew members and 6 aircraft, the Navy lost 2 aircraft, and the Army lost 1 aircraft. Service officials believe the figures in table I.1 probably include all the significant collisions, though not necessarily all the less damaging ones.

Table I.1: Number of Collisions Between Military Aircraft and Birds (1983-87)

Year	Air Force	Navy	Army	Total
1983	2,347	413	39	2,799
1984	2,321	676	76	3,073
1985	2,722	683	64	3,469
1986	2,765	744	65	3,574
1987	2,559	675	49	3,283
Total	**12,714**	**3,191**	**293**	**16,198**
Annual averages	2,543	638	59	3,240

According to service officials, the Air Force has the most collisions because it has the greatest number of low-flying aircraft. Further, we found that the Air Force puts the greatest emphasis on reporting. In contrast, Army officials said that the Army has the fewest collisions because most of its aircraft are helicopters that fly slowly, giving pilots time to see and avoid birds. Moreover, helicopters have filters or screens to protect their engines.

Bird collisions can be costly as well as tragic. Those 16,198 collisions cost the services over $318 million. (See table I.2.) Air Force losses included the crash of a B-1B bomber, a loss the Air Force estimated at $215 million.[1]

[1] The $215 million reflects the cost of the aircraft only (i.e., fly-away cost). The actual cost of the loss may be higher because other costs are not included. A recent report, B-1B Cost and Performance Remain Uncertain (GAO/NSIAD-89-55, Feb. 3, 1989), estimated the total program cost for 100 B-1B aircraft to be $31 billion, or $310 million per aircraft. However, this includes such costs as those for ground support equipment, which would not have been on the aircraft.

Table I.2: Cost of Bird Collisions With Military Aircraft (1983-87)

(Dollars in thousands)

Year	Air Force	Navy	Army	Total
1983	$4,128	$711	$17	$4,856
1984	19,394	1,602	3,778	24,774
1985	5,194	1,327	22	6,543
1986	18,000	20,611	220	38,831
1987	242,628	649	80	243,357
Total	**$289,344**	**$24,900**	**$4,117**	**$318,361**

Note: We were told that these estimates are not revised when repair work has been completed, do not include associated costs (e.g., lost fuel and clean-up), and generally do not reflect full replacement cost for aircraft losses.

These figures also include engine damage due to bird ingestion of (1) $19 million for the Air Force, (2) $1.5 million for the Navy, and (3) almost $4 million for the Army.

Aircraft Testing Process

Testing new aircraft is a critical part of DOD's acquisition process, because decisionmakers must know whether and to what extent the aircraft can meet its technical and operational requirements and perform as required in the environment in which it will operate. Testing against bird collisions is a small but important step in demonstrating that aircraft components can meet requirements.

Testing Procedures

To determine whether they will perform as specified, new military aircraft undergo two types of testing—development and operational. As part of the design process, development testing verifies that an aircraft can meet performance specifications and objectives. Operational testing estimates an aircraft's effectiveness and suitability in its intended environment when operated, maintained, and supported by personnel having the same qualifications as those who would do so in the field. According to an official from OSD's Office of the Director for Operational Test and Evaluation, military aircraft are tested against bird collisions only during development testing.

Development testing is done according to contract specifications established by the service. To have an aircraft designed and built, the service provides a request for proposals that either refers to military specifications or gives specific requirements tailored from the military specifications. For example, when a contractor responds with a bid for

developing and testing an aircraft engine, specifications for bird ingestion testing include the numbers and the sizes of birds to be ingested. Once these specifications are negotiated, the contract is awarded and the contractor conducts the testing.

According to service officials, the contractor also writes the test plan, evaluates the test results, and writes the test report. To monitor the contractor's testing process, service officials review and approve the test plan, observe the testing, and review and approve the test report. Military service representatives are not required to observe testing and when they do, they generally do not prepare reports of their observations.

Engine Test Specifications

We concentrated our review on jet engines for tactical aircraft that fly fast and low because these planes are the most numerous and susceptible to bird collisions. All three services have specifications to test military engines against bird ingestions.[2] The Navy and the Air Force use MIL-E-5007, a general military specification for jet engine testing, but in September 1985, the Air Force issued its own specification for jet engine testing, MIL-E-87231.

Both specifications call for testing against small, medium, and large birds.[3] Specifications for small birds require that the engine recover and complete its mission after ingesting up to 16 2- to 4-ounce birds at one time, depending on the size of the engine's inlet. Specifications for medium birds call for the engine to keep operating after ingesting several birds at one time, depending on the size of the engine's inlet. The Navy requires 2-pound medium size birds and the recently issued Air Force specification requires 1.5-pound medium size birds. Specifications for large birds require that the engine be able to ingest a single 4-pound bird and shut down safely and contain any damage within it.

Bird Ingestion Testing

Engines are tested for bird ingestion at the engine contractor's test facility. Set-up procedures must comply with the test plan reviewed and

[2]We were told that when a military aircraft has a commercial engine, the services accept the Federal Aviation Administration's certification that the engine can withstand bird ingestions. However, these aircraft generally do not operate fast and low for long periods.

[3]The Army has a specification for testing helicopter engines against bird ingestions, but we did not review its testing because ingestions are infrequent.

approved by service officials. The test plan, based on the engine contract and agreed to by the contractor and the military, establishes test objectives and the tasks to be performed. For example, before testing, the bird carcasses are X-rayed to ensure they are free of foreign materials that could cause additional damage upon ingestion. They are also weighed to ensure they meet test specifications. The carcasses are then loaded into a gun that is precisely targeted to the desired location inside the engine's inlet.

Test facilities use high-speed film and cameras to verify velocity and record the ingestion. A remote control panel and a device called a sequencer initiate the test. The sequencer ensures proper timing for camera start, engine conditions, and gun firing. Engine monitoring and recording equipment are also used to measure and document the ingestion, including the effect on the engine's thrust level.

Military, Federal Aviation Administration, and contractor officials agree that bird ingestion testing is very costly. Testing the ingestion of medium and large birds can cause substantial damage to an engine costing several million dollars. Moreover, ingesting a large bird could result in total loss of the engine.

Specifications and Testing for Jet Engines Are Not Realistic

Military specifications for bird ingestion testing are normally cited as general guidance, but are tailored in contracts. Recent studies of bird ingestion data indicate that neither the specifications nor the tests accurately reflect the sizes and the numbers of birds actually being ingested.

Engine Test Specifications Do Not Reflect the Sizes and the Numbers of Birds Ingested

Military specifications used by the Air Force and the Navy for testing engines against bird collisions serve as guidance rather than as requirements, and these specifications can be and are tailored. Our analysis of general military specifications, contracts, and test reports for nine military jet engines developed since the early 1970s showed that the services lowered the general military specifications for the sizes and the numbers of medium birds to be used in testing engines. The contracts contained specifications for either smaller (1.5 pounds versus 2 pounds required by MIL-E-5007) or fewer (one or none versus more than one) medium birds. This is acceptable under DOD's acquisition system because the guidance in the specifications allows for such flexibility.

According to a March 25, 1988, study of Air Force data by the Aeronautical Systems Division of the Air Force Systems Command and an October 17, 1986, study of commercial aircraft data by the Aerospace Industries Association, the size and number of medium birds actually collided with are different from those used in military aircraft jet engine testing. These studies showed the average size of medium birds being ingested is 2.5 pounds, rather than the test sizes specified by the Air Force (1.5 pounds) and the Navy (2 pounds). Also, Air Force and Navy test specifications for small and medium birds call for the ingestion of several birds at once, but study data showed that only one bird is usually ingested.

An Air Force official told us that as a result of its ingestion study, they plan to increase the specification for medium birds to 2.5 pounds and decrease the number of birds to be ingested. In addition, because separate specifications are not needed to test the same type of engine, the services are developing a common specification for testing jet engines.

Bird Ingestion Tests Do Not Reflect the Size Categories

Although design specifications for engines often specify testing for three bird sizes, our review of test records for nine jet engines used in military fighter and attack aircraft showed that the contracts do not usually require testing all three sizes. (See app. IV.) Officials told us that tests using large birds are often not required because of their potential to destroy an engine. Engines are also tested by analytical methods rather than by actual bird ingestion testing. Moreover, tests can be waived if the engine is sufficiently similar to previous versions that passed ingestion tests. If the aircraft has a commercial engine that has already been tested for the Federal Aviation Administration, the services do not retest.

Of the nine engines reviewed, we found that many were tested to withstand small birds but not medium or large birds. One engine was tested for ingesting a large bird. Other engines were tested by analysis, such as using a computer for the B-1B large bird test, that OSD test managers consider acceptable. Other engines were accepted without any testing because the military considered those engines sufficiently similar to earlier versions.

For example, the contract for the F100-PW-100 engine on the Air Force's F-15 and F-16 aircraft required designing the engine to survive the ingestion of small, medium, and large birds yet did not require testing against medium or large birds. Consequently, the engine was tested

only against small birds. Due to the time elapsed since the testing in the early 1970s, Air Force officials were unable to explain why the contract did not require testing all sizes. This omission could have greater implications for later generations of this engine. Contracts for two subsequent models (the -200 and -220) also required ingestion of all three bird sizes. However, both models were accepted without any ingestion testing because the military considered them sufficiently similar to the original -100 model, which had not been tested against medium or large birds.

Another example of an engine not fully tested is the Navy's F404-GE-400 engine on the F-18 aircraft. According to a Navy official, the contractor's proposals did not provide for bird ingestion testing. The government requested the contractor to include ingestion testing. However, because the contractor said such testing would increase costs, the government decided not to require it in the final contract. Five years later, the Navy had the original engine contractor conduct limited testing using one small bird and one medium bird.

Airframes Are Not Tested Against Bird Collisions

Although about half of all the recent bird collisions with military aircraft were strikes to the airframe[4] (see table I.3), officials told us that airframes are not tested against bird collisions and no specifications require such testing.

Airframe collisions are expensive, especially for the Air Force, which lost three aircraft at a cost of $235 million from 1983 to 1987. The most expensive loss was in 1987 when a B-1B aircraft valued at $215 million crashed because a 16-pound pelican[5] penetrated the airframe. Hydraulic fluid, fuel, and electrical lines were severed, causing fires and loss of control. After studying the crash, the Air Force decided to reinforce three areas of the B-1B airframe at a cost of $40 million. Because of testing cost and time, the Air Force tested this modification by engineering analysis rather than by actually firing birds at the reinforced areas.

[4]The airframe is the exterior of an aircraft, excluding engines and transparencies. The areas of the airframe most susceptible to collisions are those toward the front of the plane (e.g., the fuselage, nose and wing's leading edges).

[5]This bird was much larger than would normally be encountered. For tests, "large" is usually defined as a 4-pound bird.

Table I.3: Total Bird Strikes to Military Aircraft and Percentage of Strikes to Airframes

Service	Period	Total number of collisions[a]	Percentage due to airframe strikes
Air Force	1983–87	12,714	54
Navy	1981–85[b]	2,769	54
Army	1983–87	137	47

[a]Collisions for which details are available do not include all the reported bird collisions in table I.1

[b]Most recent 5-year period for which Navy data was available

OSD development test officials believe that critical airframe areas may need to be tested. These test officials further believe that tests for vulnerability[6] would ensure that the airframe is adequately designed to withstand bird strikes. However, OSD's Director for Live Fire Testing disagreed. He does not believe that tests for vulnerability could realistically reflect how the airframe would withstand a bird strike because of the differences between a bird and a "hard" projectile. These differences include such things as weight, size, and velocity at impact.

DOD Performs Limited Oversight of Contractor Testing Against Bird Collisions

The services' role in testing military aircraft against bird collisions is primarily that of a monitor. The engine and the transparency are the only parts of military aircraft that are required to be tested against bird collisions. Officials described the military's role in testing both parts as being basically the same—the contractor performs the testing and the military monitors the test process. We concentrated our work on government observation of engine testing against bird ingestions. According to OSD and service officials, contractors write the test plans, conduct the tests, evaluate the test results, and prepare the test reports. Service officials review and approve the test plans, observe the tests, and approve the contractor reports of test results.

The Services Do Not Have Specific Guidance on Observing Tests

The services' monitoring of testing is largely informal. Service representatives are not required to observe engine testing against bird collisions, but local government representatives stationed at the engine manufacturer's plant may observe the tests at the request of the buying command. The government representatives told us that OSD and the services have not given them guidance on observing, nor could we find any guidance. Moreover, the oral requests to observe were undocumented. According to these government representatives, they can and sometimes

[6]Live-fire testing, for example, is a form of testing used by the military to determine how well its weapon systems can withstand hits by enemy projectiles.

do take the initiative to check some of the testing equipment during their observations.

Documentation of Test Observations

Documentation is usually not prepared when test observations are made. As a result, it is difficult to determine whether contractor tests are performed in accordance with contract requirements as outlined in test plans.

To better understand DOD's use of observation in the monitoring process, we visited two engine contractor plants that had tested three fighter aircraft engines against bird ingestions since 1980. For two of the engines tested (the F110-GE-100 tested in 1984 and the F110-GE-400 tested in 1985), so little information was available that we could not determine whether government observers had actually attended the tests. For the third engine (the F100-PW-229 tested in 1987), we did find informal notes of observations. However, the documentation was not adequate to evaluate to what extent specifications were met or if internal controls ensured that tests were conducted as required.

Status on Development of Nonflammable Hydraulic Fluid

Research on developing a nonflammable hydraulic fluid has been ongoing since the 1960s. Hydraulic fluids currently used in aircraft are highly flammable and have contributed to both loss of aircraft and significant aircraft damage. A nonflammable hydraulic fluid has been developed by the Air Force but cannot be used yet because it is incompatible with existing systems. According to Air Force officials, while it might be used for new systems under design, no new aircraft have been committed to using it because the necessary hydraulic components and systems are not yet available.

Hydraulic fluid fires can be serious. From 1965 to 1986, the Air Force had at least five fatalities and 19 injuries and lost $237 million in aircraft accidents where hydraulic fluid was the primary source of a fire or contributed to increasing the severity of a preexisting fire.

Hydraulic Fluids Currently in Use

Military aircraft currently use MIL-H-5606 and MIL-H-83282. The first fluid is flammable, and the second one, though fire-resistant, will still burn.[1] Except for the Strategic Air Command, the Air Force switched to MIL-H-83282 in the early 1980s. Air Force officials believe that this change decreased the number of hydraulic fires. The Strategic Air Command still uses MIL-H-5606 because that fluid is necessary to its aircraft operations that are carried out at lower temperatures. The Navy also uses MIL-H-83282, while the Army uses both fluids.

Development of Nonflammable Hydraulic Fluid

We were told that since the 1960s, the military had tried but failed to develop a nonflammable hydraulic fluid compatible with existing aircraft systems. In 1975, the Air Force began to develop a nonflammable hydraulic fluid without considering the compatibility of existing hydraulic systems. By the early 1980s, the Air Force had developed a nonflammable hydraulic fluid, CTFE.[2] However, CTFE is not compatible with existing hydraulic systems because it is denser (weighing twice as much) and thus, requires larger openings to flow through. CTFE is estimated to cost more than existing fluids, but the quantity needed is estimated to be less than that used in current systems.

[1] Preliminary results of recently completed joint live fire testing, described in a September 1, 1988, memorandum from the Director of Live Fire Testing, showed that while the fire-resistant MIL-H-83282 hydraulic fluid is a better performer when no airflow is present, it is much worse than MIL-H-5606 when airflow is present, which is typical at combat velocities. It then burns twice as often when hit and burns longer and with hotter temperatures.

[2] The Navy and the Army, recognizing CTFE as nonflammable, are no longer working to develop a nonflammable aircraft hydraulic fluid.

Since 1975, the Air Force has spent at least $21 million to develop the nonflammable fluid and compatible components. (See table II.1.) This amount includes contract costs and the cost of government equipment. However, it does not include costs for two government engineers and one technician to do research, government contract administration and management, and toxicity research because cost data for these efforts were not readily available.

Table II.1: Air Force Cost to Develop Nonflammable Hydraulic Fluid and Components (1975-88)

(Dollars in thousands)

Item	Cost
Contracts for fluid development	$7,558
Government equipment	796
Contracts for component development	13,298
Total	**$21,652**

Source: Air Force Systems Command.

Plans to Use Nonflammable Hydraulic Fluid

Air Force officials believe that retrofitting aircraft with hydraulic systems that could use CTFE would not be cost effective although they have not estimated the cost. The Air Force has successfully tested a C-135 aircraft using CTFE in a modified brake system, and officials told us that the Army has tested CTFE in M-1 tank gun turrets. The Air Force has concentrated on developing hydraulic components that can use CTFE. Final testing of these components for new aircraft is scheduled for 1990. Additives to protect seals and metals are also under development, and the toxicity of CTFE and other fluids is being studied.

According to Air Force officials, no aircraft under development or design has yet been committed to use CTFE because the necessary hydraulic components and systems are still being designed and tested and design decisions on these new weapon systems have not yet been made. Managers for the Advanced Tactical Fighter program have been directed to consider CTFE, but it will be 2 years before the design decisions will be made. We were also told that the Army's program managers for the new family of tracked vehicles have been provided information on CTFE for consideration.

Nontesting Measures to Reduce Risk to Aircraft

We reviewed nontesting measures that could reduce the risk that birds present to aircraft. This appendix describes the status of these measures.

Reduction and Avoidance Efforts to Minimize Bird Collisions

The services take different approaches to bird hazard reduction and avoidance, based on their perception of the problem's significance. The Air Force has taken the lead in reduction and avoidance efforts because it has experienced the most significant losses.

The services are pursuing three primary means to reduce bird collisions: (1) making airfields less attractive habitats for birds, (2) planning routes to avoid bird habitats and migratory patterns, and (3) identifying and reporting the location of flocks around airfields and during flight.

Reducing the Attractiveness of Airfields to Birds

Making an area unattractive to birds as a habitat or feeding ground is important because about one-half of the military's bird collisions occur during aircraft take-offs, approaches, and landings.[1] This has been done by closing landfills on or near airfields, cutting airfield grasses, removing standing water and foliage, and playing recordings of predatory birds near runways.

The services' approaches to field management differ. The Air Force requires each base with a flying mission to develop a bird hazard reduction plan and to establish an on-site group of personnel to monitor and resolve bird problems. The Navy and the Army have no requirement for bird hazard reduction planning, although the Navy provides guidance in a pamphlet that airfield commanders can use. Navy airfield commanders make some effort to get rid of birds, but not on a systematic basis.

The effectiveness of bird hazard reduction efforts varies from airfield to airfield depending on command emphasis. We were told by the Air Force's Bird Aircraft Strike Hazard (BASH) team members and the official heading the Natural Resources Branch within the Naval Facilities Engineering Command that airfield commanders and major commands that own the aircraft decide what resources will be spent. The Army takes action only when birds become a major problem at a specific airfield. The Army's bird collision data supports its position that it does not have a significant problem. (See tables I.1 and I.2.)

[1] About 54 percent of Air Force encounters (1983-87) and 64 percent of Navy encounters (1981-85).

Planning Routes to Avoid Birds

Using information about where birds are likely to be flocking or migrating before take-off can reduce bird collisions during low-level operations. These collisions represent 24 percent of the Air Force's total bird collisions for 1983-87. The Navy's data for 1981-85 showed 19 percent.

The Air Force's BASH team has developed a bird avoidance model to predict the likelihood of encountering migrating waterfowl and large raptors (e.g., eagles or hawks) on specific routes. The BASH team is expanding the model; however, according to Air Force officials, more funding is needed for data collection, computerizing the data base, and validating the model. According to BASH team officials, the Strategic Air Command has had two of its route planners trained in this model to lessen the probability of bird collisions with its B-1B aircraft.

Using Radar to Avoid Birds

The BASH team is also trying to incorporate a "bird recognition algorithm" in the Next Generation Weather Radar System now under development to provide a comprehensive means to identify and report bird activity near airfields. This system, which is being built as a joint project by the National Weather Service, the Federal Aviation Administration, and the Air Force's Air Weather Service, is intended to more accurately identify and report severe weather for about 80 percent of the continental United States.

Other Efforts of the Services' Bird Avoidance Organizations

The Air Force and the Navy offices that deal with bird hazard reduction and avoidance provide advice and support and are trying to make commands more aware of actions needed to address bird hazards.

The BASH team also assists the Navy, the Marine Corps, the National Aeronautics and Space Administration, and foreign governments in their bird hazard reduction and avoidance efforts.

The Naval Facilities Engineering Command's Natural Resources Branch plans to formalize and coordinate Navy bird hazard reduction efforts and make them mandatory at Navy airfields without significantly increasing costs. Navy commands owning or operating aircraft have not agreed to support this plan but the Marine Corps did support it. Naval Air Forces-Atlantic Fleet and Office of the Chief of Naval Operations (Air Warfare) officials told us they do not believe the Navy's bird hazard problems are significant enough to require changes, and bird collision data may support this.

Air Force Redesign of Aircraft Transparencies When Missions Are Changed

Birds striking and penetrating transparencies (the clear panels used to see out of the cockpit) have caused the loss of pilots and damage to and/or loss of aircraft. Between 1983 and 1987, the Air Force lost two crew members and suffered $17 million in damages from 2,417 collisions of aircraft and birds—strikes to windscreens, canopies, or other parts of aircraft transparencies, including 51 penetrations and the loss of an aircraft.

The Air Force recognized the need for transparency redesigns for aircraft when mission requirements changed to flying low,[2] fast missions. By increasing the impact resistance of some transparencies, the Air Force estimates it has saved $420 million.[3] However, transparencies for other aircraft (i.e., the F-15E and the F-16) that have been assigned missions to fly lower have not yet been redesigned, but these aircraft have not experienced significant losses.

The current requirement for low-level operations is to survive a collision with a 4-pound bird at maximum level flight speed, according to Air Force and Navy researchers. For tactical (fighter and attack) aircraft, they define this to be resistance to 500 knots.

The Air Force has been aware of the need to redesign and test[4] transparencies for aircraft that do not meet mission requirements for flying low, fast missions.

Other Transparencies Have Not Yet Been Redesigned

According to Air Force officials, the F-15E (unlike the earlier "A" to "D" versions) has a ground attack role which requires it to fly low and fast missions. Consequently, the windscreen was redesigned for 450-knot collision resistance. However, its overhead canopy, a significant part of the front of the transparency system,[5] is resistant to collisions only up to 180 knots. Tactical Air Command officials told us that the canopy has

[2]Statistics for the Air Force and the Navy have shown that collisions with birds occur more frequently below an altitude of 1,000 feet.

[3]Air Force transparency researchers estimated these savings for two types of aircraft over the past 13 years. This figure reflects $260 million for the value of 20 F-111 aircraft that had or would have had transparency collisions plus 1 F-4 struck by a bird but not lost and $160 million by not having to design a new lighter ejection system for the F-111 because the redesigned transparency was lighter.

[4]According to Air Force officials, the aircraft contractor is responsible for testing transparencies against bird hazards. As with engine testing, the service's role in transparency testing is that of a monitor.

[5]Estimated at 25 to 33 percent by the F-15 System Program Office.

not been redesigned because there has been little operational experience with the aircraft (delivery of the F-15E was scheduled to start in late 1988); also, they told us that they do not view this problem to be as significant as others they have.

The transparency of the F-16 also does not meet the requirement for bird impact resistance. Designed for high-flying, air-to-air superiority missions, it has a 350-knot resistance. However, we were told that low, fast (ground attack) flying has been part of the F-16's mission since it entered service in 1979. Bird collisions with the F-16's transparencies have occurred frequently with only minor damage, except for one loss. Between 1983 and 1987, F-16 transparencies were hit by birds 232 times, with damages estimated at over $300,000. In January 1989, according to Air Force officials, an F-16 valued at $10.3 million was lost due to a bird striking and penetrating its transparency. Before this loss, Tactical Air Command officials believed that the transparency posed a less significant problem than others they have had.

Extent of Testing to Withstand Bird Ingestions for Nine Operational Engines

Engine	Aircraft	Service	Date of test report	Tested by ingestion	Evaluated by analysis	Accepted by similarity	Not tested for birds
F100-PW-100	F-15A-D	Air Force	1972	x[a]	-	-	-
F100-PW-200	F-16A-D	AF/ANG[b]	Unknown	-	-	x[c]	x
F100-PW-220	F-15C-E F-16C-D	Air Force	None	-	-	x[c]	x
F110-GE-400	F-14A	Navy	1984	x[ad]	x[e]	-	-
F101-GE-100	F-16C,D	Air Force	1985	x[ad]	x[e]	-	-
F101-GE-100	B-1A	Air Force	1976	x[ae]	x[d]	-	-
F101-GE-102	B-1B	Air Force	1983	-	-	x[f]	x
TF30-PW-414	F-14A	Navy	None	-	-	-	x
F404-GE-400	F/A-18	Navy	None	-	-	-	x

[a]Small birds

[b]Air Force/Air National Guard

[c]Accepted because of similarity to F100-PW-100 engine

[d]Medium birds.

[e]A large bird.

[f]Accepted because of similarity to F100-GE-100 engine.

Objective, Scope, and Methodology

The former Chairman of the Subcommittee on Legislation and National Security, House Committee on Government Operations, asked us the following questions:

- What are the specifications for testing military aircraft against bird hazards?
- Have these specifications been relaxed on particular aircraft or engine programs?
- What is the nature of the relationship between engine contractors and the government during test operations?
- To what extent does the government observe or participate in the testing?
- What consideration has been given to the use of nonflammable hydraulic fluid in aircraft to prevent fires?
- What issues have been identified in testing, and what actions have been taken by safety boards and/or DOD's acquisition community to resolve them?

We reviewed how DOD tests aircraft to withstand bird collisions, focusing on (1) the processes used, (2) the specifications, (3) the relationship between engine contractors and the military during testing, and (4) the status of development and use of nonflammable hydraulic fluid. We also examined efforts to reduce and avoid bird collisions (to complement testing) and transparency redesign on F-15 and F-16 aircraft.

The military services provided us data on bird strikes and ingestions for 1983-87 from their safety centers. In addition, we analyzed computer data provided by the Air Force's BASH team. We also obtained guidance and reports on bird collisions from the BASH team and the Naval Facilities Engineering Command's Natural Resources Branch. Since statistics showed the Army had a relatively small bird collision problem, we concentrated our review on the Air Force and the Navy.

To evaluate the services' testing procedures and practices and determine which specifications were being followed in bird collision testing, we interviewed officials at and obtained documents from the Air Forces' Aeronautical Systems Division and the Naval Air Systems Command. To determine what testing the Army does, we obtained test specifications and reports from the Army Aviation Systems Command. We also discussed the results of our review with officials in the Office of the Director of Defense Research and Engineering and the Office of the Director of Operational Test and Evaluation.

To determine whether the services were following the specifications for bird collision testing, we reviewed test specifications, contracts, and test reports for Air Force and Navy aircraft engines tested by two engine contractors. (See app. IV.) We discussed with contractors and the services, the differences between the testing called for by the specifications and contracts and the actual testing performed. We also discussed differences between military and commercial aircraft engine testing with officials of the Federal Aviation Administration.

To determine the relationship between the contractor and the government during tests to withstand bird collisions, we discussed the role of each with engine contractors, service representatives at the contractors' plants, and officials of the Air Force Aeronautical Systems Division and the Naval Air Systems Command. We also selected Air Force and Navy engines tested by the two engine contractors since 1980, reviewed all documentation showing what the service representatives had done regarding these specific tests, and discussed our findings with service and contractor representatives. We also discussed the services' roles in testing aircraft against bird collisions with the DOD offices responsible for both development and operational test and evaluation.

To determine what had been learned from aircraft tests and accidents with birds, we interviewed officials in (1) the Air Force Systems Program Offices responsible for managing the development of aircraft under procurement, and/or research and development, (2) the Air Force Wright Aeronautical Laboratories responsible for research on aircraft, engines, components, and materials, (3) the Naval Air Systems Command, and (4) the BASH team.

To determine the status of development and use of nonflammable hydraulic fluid, we did an extensive literature search. We discussed the development of both the fluid and system components that use it with research engineers at the Wright Aeronautical Laboratories and obtained a film of testing and briefing documents concerning fluid and component status. We also discussed toxicity testing with researchers at the Harry G. Armstrong Aerospace Medical Research Laboratory. In addition, we contacted officials in the Naval Air Systems Command and many offices within the Army to determine the extent of research performed on nonflammable hydraulic fluid.

To complement our study of bird collision testing, we obtained information on nontesting measures to minimize bird collisions by reducing the presence of birds near airfields and avoiding birds during flight. To

accomplish this, we interviewed members of the BASH team and officials in the Naval Facilities Engineering Command responsible for such efforts to determine what they were doing and obtained their views on impediments to more effective reduction and avoidance. With officials of the Air Force Tactical Air Command and the Naval Air Force of the Atlantic Fleet, we discussed the emphasis being placed on bird hazard reduction and avoidance. We visited airfields belonging to all three services and discussed what they were doing to minimize bird hazards. We visited Fort Rucker, Alabama, and the following sites in Virginia:

- Langley Air Force Base, Hampton;
- Naval Air Station, Norfolk;
- Ocean Naval Air Station, Virginia Beach; and
- Fort Eustis, Newport News.

We did not make a reliability assessment of the bird collision statistics provided, but were told that the data probably does not include all collisions. Further, the damage costs may be inaccurate because the services do not revise cost data to reflect (1) actual repair costs, (2) associated costs such as clean-up, and (3) replacement costs for lost aircraft.

Our review was performed between March and December 1988 in accordance with generally accepted government auditing standards.

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